INVENTIONS & INNOVATION

Project Fact Sheet

Functionally Graded Materials for Improved High-Temperature Performance of Nd-Fe-B-Based Permanent Magnets

Benefits

- Improves the performance of $Nd_2Fe_{14}B$ magnets at elevated temperatures
- Retains high-saturation magnetization and coercivity of $Nd_2Fe_{14}B$-based magnets
- Increases the performance and efficiency of electric motors and generators with the use of high-energy product $Nd_2Fe_{14}B$ magnets
- Reduces the size and weight of motors and generators used in manufacturing assemblies and transportation, saving energy
- Reduces size of the lead-acid storage battery needed in vehicles, reducing lead-use impacts and energy consumption

Applications

The new functionally graded materials for improved high-temperature performance of Nd-Fe-B-based permanent magnets is applicable to a wide range of industrial and automotive uses, particularly in motors and generators. $Nd_2Fe_{14}B$-based magnets could make starter motors lighter, provide permanent-magnet, direct current (DC) motor-driven electric steering assistance, and reduce the size of lead-storage batteries needed by vehicles.

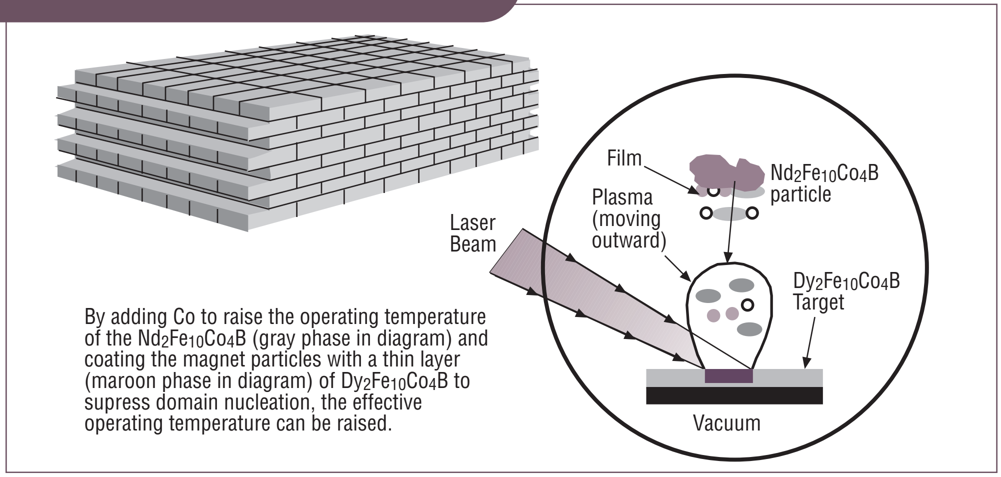
New compositionally graded microstructure for $Nd_2Fe_{14}B$-type magnets creates high-energy permanent magnets for high-heat industrial environments

Neodymium/iron/boron ($Nd_2Fe_{14}B$) magnets provide the highest energy product of all permanent magnets, offering superior performance for motors and generators through increased efficiency with reduced weight and volume. To date, application of $Nd_2Fe_{14}B$ magnets has been limited because their energy product declines at elevated temperatures, decreasing substantially when heated to 150° Celsius (C) and dropping to zero at 312°C. Because of these limitations, $Nd_2Fe_{14}B$ magnets in their current form cannot be used in automobile engine compartments or in high-temperature industrial environments.

The production of functionally graded materials for improved high-temperature performance of Nd-Fe-B-based permanent magnets would allow the useful operating temperature of these magnets to increase by 115°C. $Nd_2Fe_{14}B$-based magnets could then be used to improve the efficiency of electric motors and generators in high-temperature applications where lower-energy field coil magnets, ferrite, Alnico, or $SmCo_5$ are now used for magnet components.

A new processing method under development at Iowa State University produces a graded-composition microstructure in magnets by using pulsed-laser deposition to coat each grain of $Nd_2Fe_{10}Co_4B$ core material with a dysprosium/iron/cobalt/boron ($Dy_2Fe_{10}Co_4B$) outer layer. The resulting magnet offers a high-energy product that can withstand the elevated temperatures required in some industrial environments.

New Nd-Fe-B-Based Permanent Magnets



By adding Co to raise the operating temperature of the $Nd_2Fe_{10}Co_4B$ (gray phase in diagram) and coating the magnet particles with a thin layer (maroon phase in diagram) of $Dy_2Fe_{10}Co_4B$ to supress domain nucleation, the effective operating temperature can be raised.

New $Nd_2Fe_{14}B$ permanent magnets increase the performance and efficiency of electric motors and generators due to their ability to operate at higher temperatures than possible with conventional permanent motor magnets.

Project Description

Goal: Develop a process for producing a graded-composition microstructure in $Nd_2Fe_{14}B$ magnets that will increase the magnets' Curie temperature and decrease the temperature dependence of coercivity while maintaining their high-energy product.

This innovative process coats each grain of magnet core material with a dysprosium-rich, high-coercivity material. The center core of the grains is comprised of $Nd_2Fe_{10}Co_4B$, which provides a high-energy product. Unlike uniform-composition grains, this graded-composition approach offers a high-energy product with less loss of coercivity or performance at higher temperatures.

The functionally graded microstructure particles are produced by depositing $Dy_2Fe_{10}Co_4B$ onto $Nd_2Fe_{10}Co_4B$ powder particles using pulsed-laser deposition. In this process, a laser beam strikes a target within an ultrahigh vacuum chamber, producing a plasma plume that then condenses onto the material to be coated. The powder particles are rotated under the plasma plume to promote even and controlled coating deposition. These coated powders may then be sintered to produce bulk magnets.

Iowa State University is developing this new technology with the help of a grant funded by the Inventions and Innovations Program in the Department of Energy's Office of Industrial Technologies.

Progress and Milestones

- Design and assemble ultrahigh-vacuum pulsed-laser deposition chamber with provision for rotating powder particles in the plasma plume and sealing to prevent contamination.
- Conduct trial runs of coating $Nd_2Fe_{10}Co_4B$ powder with $Dy_2Fe_{10}Co_4B$.
- Optimize process parameters for achieving desired coating quality in minimum time.
- Perform analysis of coated-powder particles to measure depth and uniformity results of each trial coating run.

Economics and Commercial Potential

The potential for cost, energy, and environmental savings associated with functionally graded materials for improved high-temperature performance of Nd-Fe-B-based permanent magnets is large. Sales of $Nd_2Fe_{14}B$ magnets already exceed $2 billion per year, and increasing their application in high-temperature environments would expand the market even further.

Markets in the automotive industry are particularly promising. For example, the $Nd_2Fe_{14}B$-based permanent magnets could replace the magnets used in automobile starter motors. The new material would allow the starter motors to be smaller and lighter and would eliminate the need for a gear-box on the starter motor because the increased torque could turn the engine crankshaft directly. Additionally, a lighter lead acid battery could be used to start the car, saving the vehicle weight and reducing total lead use in the battery. The potential weight reduction of approximately 14 pounds per vehicle would add an estimated .11 mile per gallon per vehicle, with a savings of $160,000,000 yearly in the United States.

In addition, hydraulic-power steering units that are continuously powered could be replaced with permanent-magnet, DC, motor-driven electric steering assistance that draws power only when the vehicle is turning. Complete conversion of hydraulic power steering could result in saving approximately 2,400,000 barrels of oil per year.

The Iowa State University Research Foundation is expected to patent this technology and then negotiate licensing arrangements with prospective users, primarily existing $Nd_2Fe_{14}B$ magnet production companies.

The Inventions and Innovation Program works with inventors of energy-related technologies to establish technical performance and conduct early development. Ideas that have significant energy savings impact and market potential are chosen for financial assistance through a competitive solicitation process. Technical guidance and commercialization support are also extended to successful applicants.

Project Partners

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